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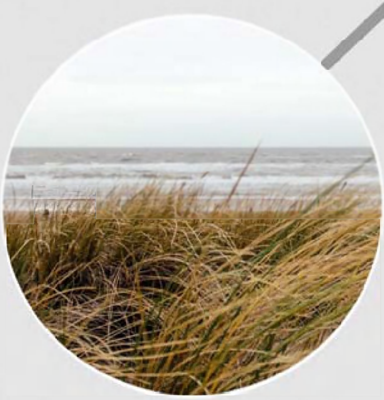

Technical Memorandum

Conceptual Model for Nearshore Exposure to Deepwater Horizon Oil

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September 4, 2015

• Deepwater Horizon Oil Spill •

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TECHNICAL MEMORANDUM

SUBJECT: Conceptual Model for Nearshore Exposure to Deepwater Horizon Oil

DATE September 4, 2015

TO: Mary Baker, NOAA; Marla Steinhoff, NOAA

FROM: Mengni Zhang, NewFields; Jacob Oehrig, NewFields; Shahrokh Rouhani, NewFields

On April 20 2010, an explosion aboard the Deepwater Horizon (DWH), a Gulf of Mexico (GOM) offshore oil rig, resulted in the largest oil spill in US history. Beginning in May, satellite and other information demonstrated that floating oil entered the nearshore environment of the northern GOM (Graettinger *et al.*, 2015). The oil eventually stranded on shorelines as tar balls and emulsified oil, affecting more than 2,000 kilometers of shorelines (Nixon *et al.*, 2015), mixing with nearshore sediments, or sinking to form submerged oil mats. Relying on the extensive available chemistry and forensic data, a conceptual model for nearshore exposure to DWH oil was developed.

The investigated nearshore chemistry and forensic data represented locations within 500 meters (m) of the shore, and covered a wide area of the northern GOM, as listed in Table 1 and displayed in Figure 1. The primary exposure data summarized here are total polycyclic aromatic hydrocarbon (tPAH) surrogate corrected concentrations, which were calculated using the toxPAH50 formula available in DIVER (https://dwhdiver.orr.noaa.gov).

Submerged sediment forensic results indicated wide-spread presence of DWH oil along the affected shorelines of the northern GOM, as displayed in Figure 2 (Emsbo-Mattingly and Martin, 2015). The forensic results were also utilized to identify ambient representative samples. Ambient representative samples were those samples that had been forensically identified as code D, while being at least 100 m from any DWH oil manifestation. This included oiled segments or sites observed by various survey teams, DWH confirmed oil, tar ball, sheen, soil, sediment, or tissue samples. The 100 m buffer was included in order to minimize the chances of having diluted DWH oil in ambient representative samples. Table 2 provides summary statistics of ambient representative nearshore tPAH concentrations for submerged sediments. The highest ambient tPAH concentrations occurred offshore of the Mississippi River Delta and the lowest occurred offshore of the coastal wetlands of Louisiana's barrier islands. In general, ambient tPAH concentrations within the first 50 m of the shore were slightly higher than those measured beyond 50 m.

Submerged sediment data collected in 2010 and 2011, especially within the first 50 m of oiled shorelines, displayed patchy distributions of elevated tPAH concentrations in excess of ambient levels, as listed by their summary statistics in Tables 3 and 4 and depicted in Figures 3 through 6. All summary statistics for data based on stratified random samplings were calculated following survey procedures (Cochran, 1977) and performed using R package *survey* (R version 3.2.0) and verified by SPSS *Complex Samples* (IBM SPSS version 23).

Wetland soil forensic results also indicated extensive presence of DWH oil in marsh areas of the northern GOM, and the highest tPAH concentrations, orders of magnitude higher than the ambient concentrations, were detected, especially along the seaward edge of marshes. Over time, PAHs exhibited evidence of weathering in both submerged sediments and wetland soils (Table 5), though continued to exceed ambient concentrations by orders of magnitude in the most heavily oiled areas. These observations were synthesized in a pictorial model based on the result of DWH oil confirmed samples in various nearshore components of Louisiana mainland herbaceous salt marsh shorelines, as depicted in Figure 7. The elevated standard deviations of tPAHs in this figure highlight the patchy distribution of DWH oil throughout the nearshore environment.

Reference

Cochran, W.G. Sampling Techniques, 3rd ed.; John Wiley & Sons: New York, NY, 1977.

Emsbo-Mattingly, S.; Martin, C. 2015. Distribution and Weathering of Macondo oil in Nearshore Soils, Sediments, and Tissues Collected between Spring 2010 to Spring 2012 Based on Chemical Fingerprinting Methods. NOAA.

Graettinger, G.; Holmes, J.; Garcia-Pineda, O.; Hess, M.; Hu, C.; Leifer, I.; MacDonald, I.; Muller-Karger, F.; Svejkovsky, J.; Swayze, G. 2015. Integrating Data from Multiple Satellite Sensors to Estimate Daily Oiling in the Northern Gulf of Mexico during the Deepwater Horizon Oil Spill. NOAA.

Nixon, Z.; Zengel, S.; Michel, J. 2015. Shoreline Oiling from the Deepwater Horizon Oil Spill. NOAA

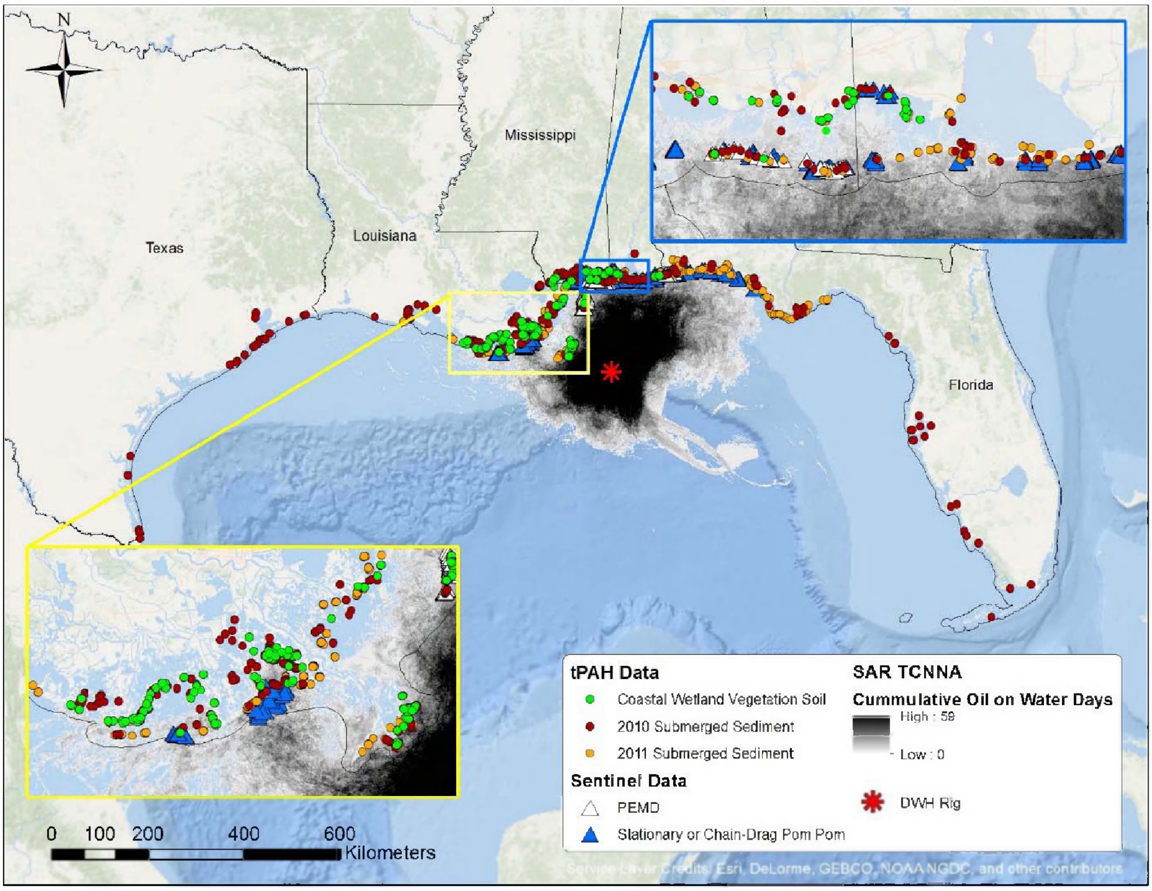

Figure 1. Investigated nearshore chemistry data.

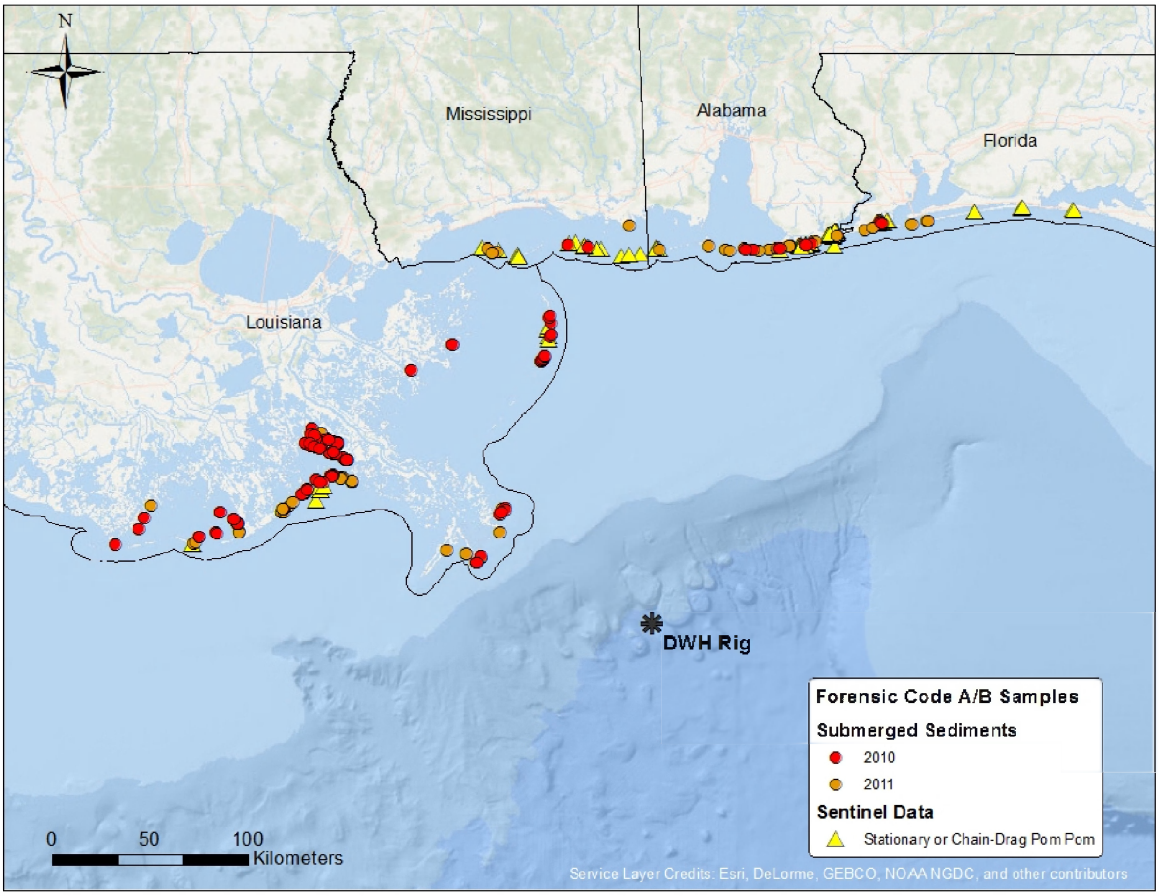

Figure 2. Spatial distribution of forensic code A and B samples.

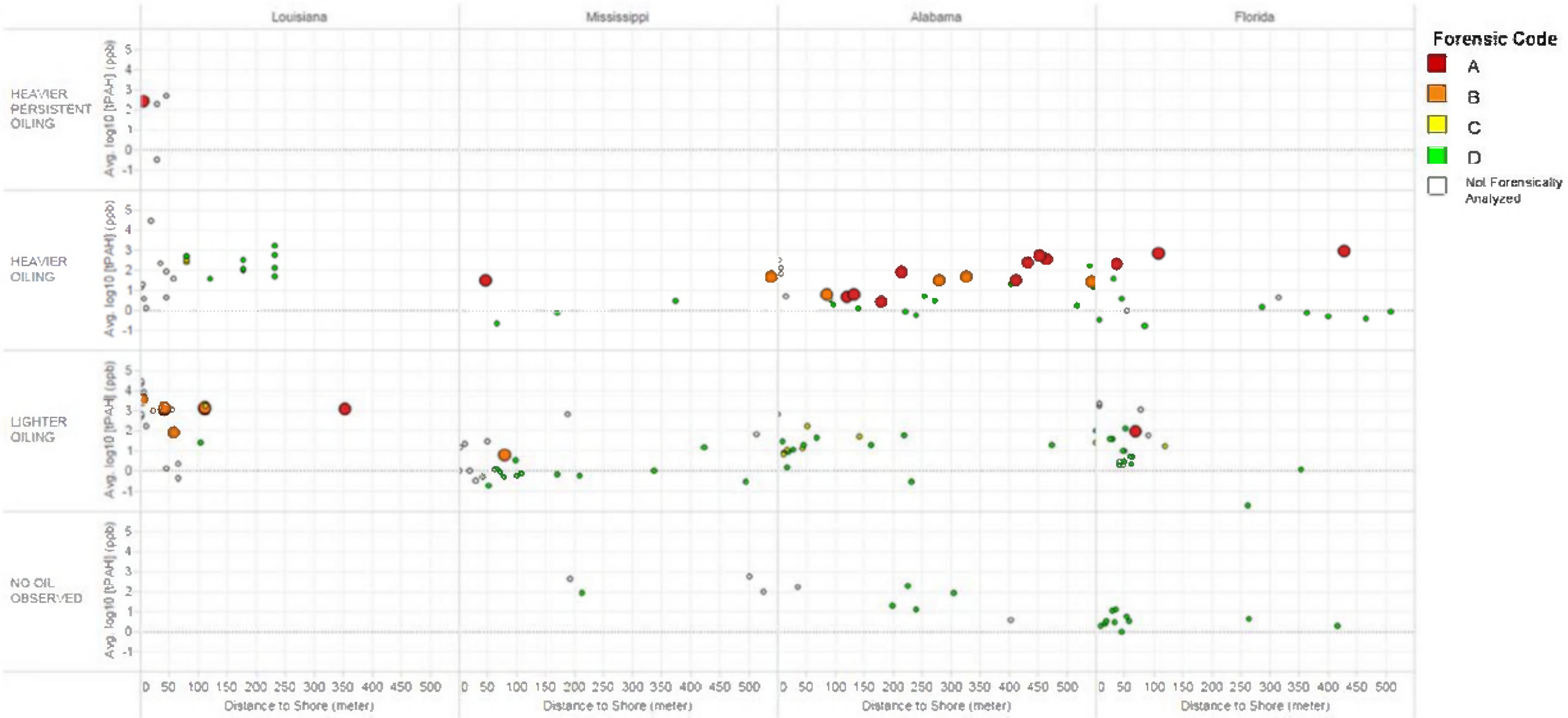

Figure 3. 2010 post-spill nearshore tPAH concentrations *versus* distance to shore along non-vegetated shorelines.

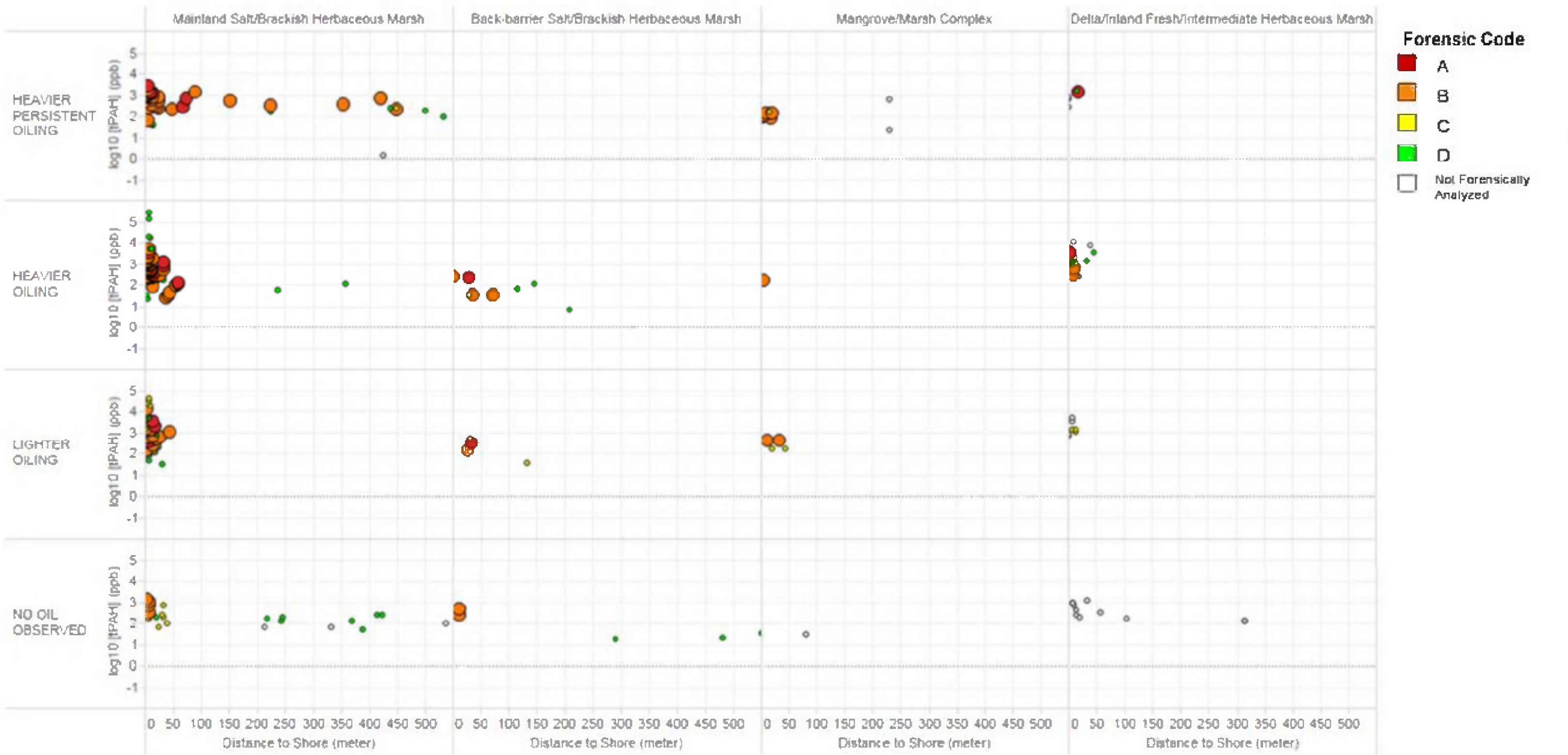

Figure 4. 2010 post-spill nearshore tPAH concentrations *versus* distance to shore along vegetated shorelines in Louisiana.

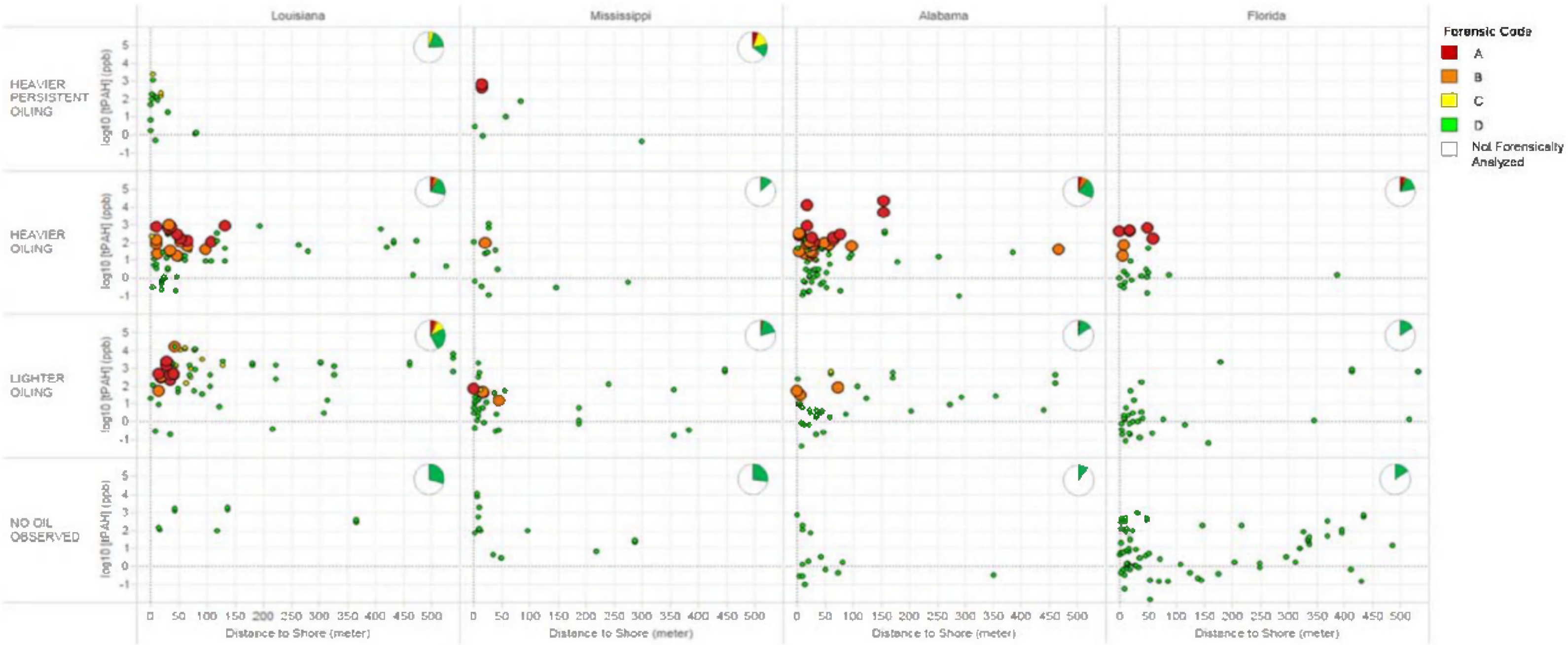

Figure 5. 2011 MESSh nearshore tPAH concentrations *versus* distance to shore along non-vegetated shorelines.

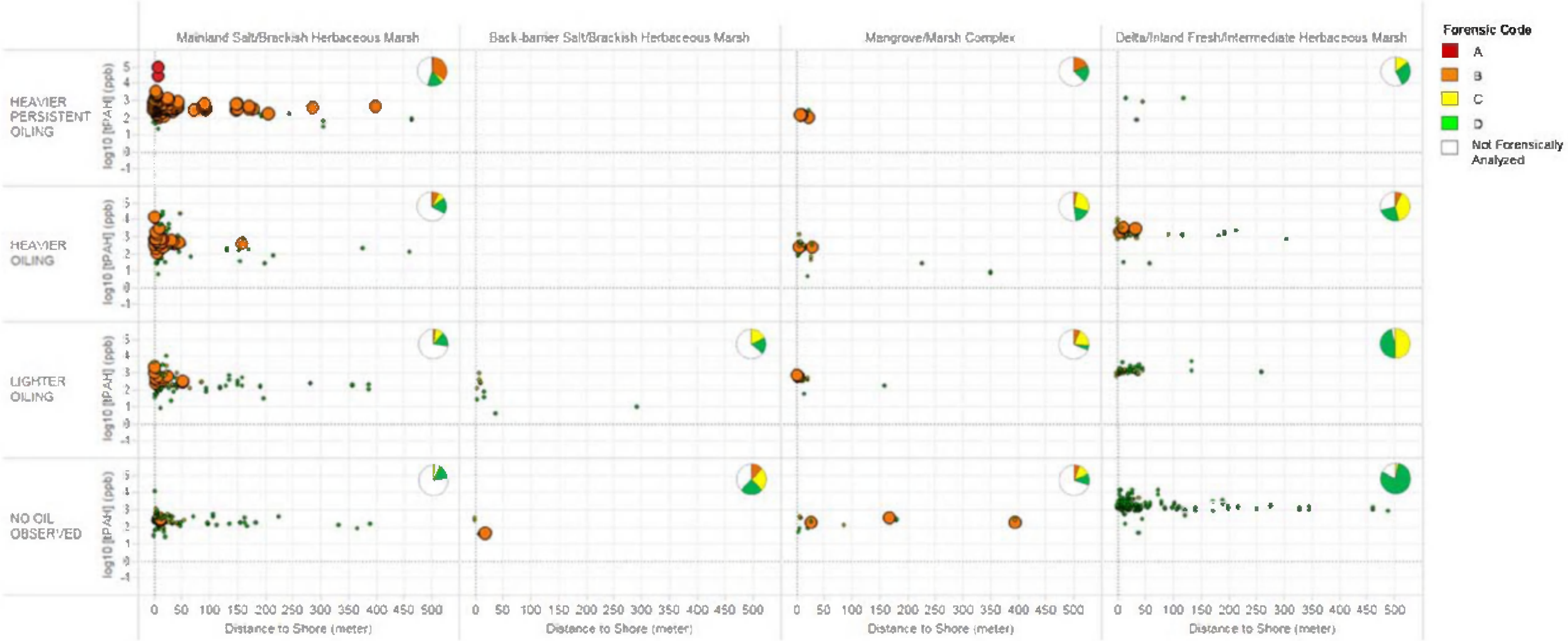

Figure 6. 2011 MESSh nearshore tPAH concentrations *versus* distance to shore along vegetated shorelines in Louisiana.

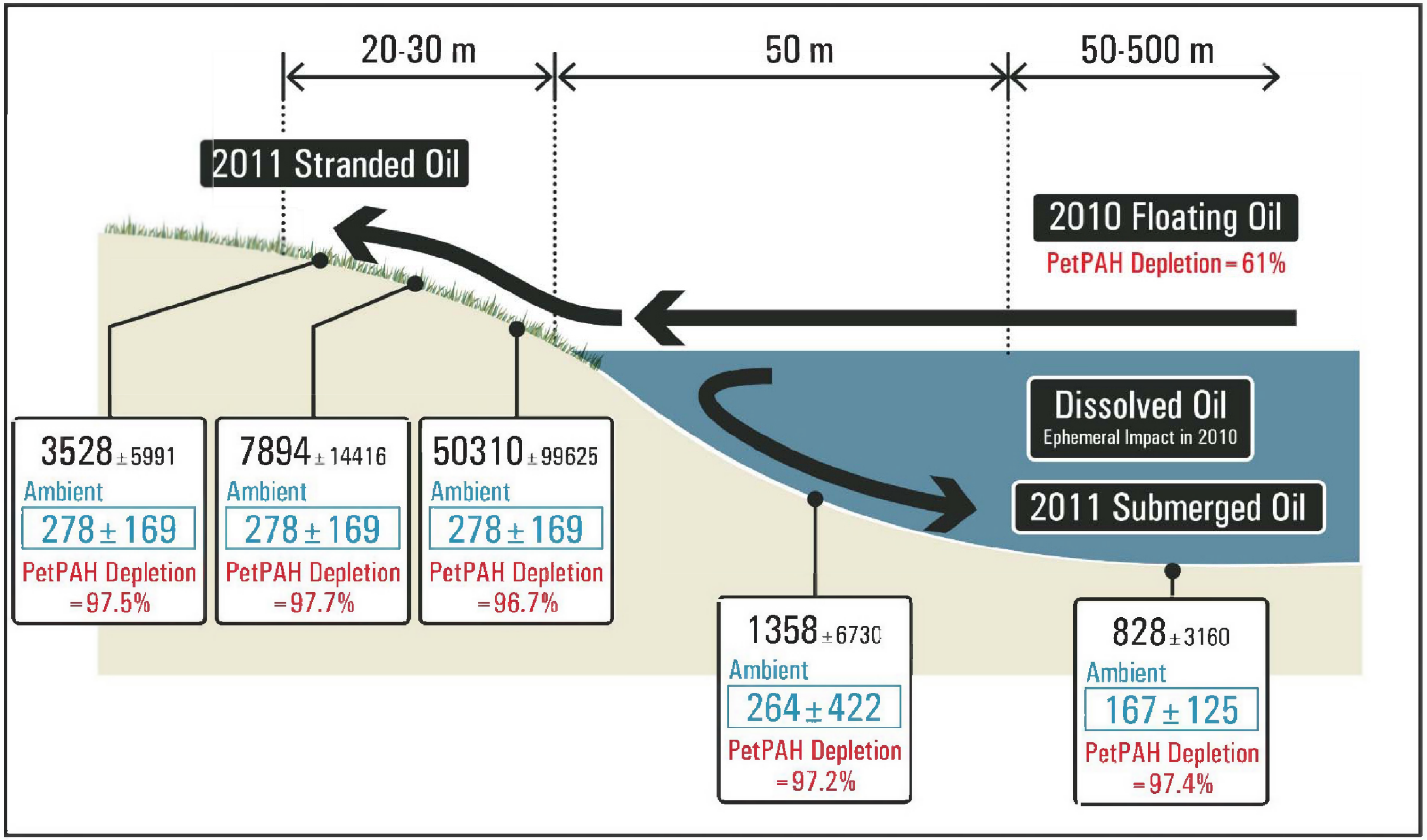

Figure 7. Conceptual model of nearshore exposure to DWH oil based on forensic code A/B samples along Louisiana mainland herbaceous salt marsh shorelines.
(Average tPAH concentrations ± standard deviations are displayed in black. Ambient tPAH concentrations ± standard deviation are displayed in blue. Average petrogenic PAH depletion rates in percent are shown in red.)

Table 1. Count of submerged nearshore sediment samples with tPAH results.

Shoreline Oiling Category	Shoreline Type	Sample Size (2010 / 2011)				
		Louisiana	Mississippi	Alabama	Florida	Texas
HEAVIER PERSISTENT OILING	Vegetated	64 / 161	0 / 0	0 / 0	0 / 0	0 / 0
	Non-Vegetated	15 / 17	1 / 7	0 / 0	0 / 0	0 / 0
HEAVIER OILING	Vegetated	139 / 180	0 / 0	0 / 0	0 / 0	0 / 0
	Non-Vegetated	38 / 65	8 / 14	35 / 85	33 / 36	0 / 0
LIGHTER OILING	Vegetated	98 / 229	1 / 17	3 / 2	0 / 0	0 / 0
	Non-Vegetated	42 / 68	45 / 39	29 / 38	40 / 34	17 / 0
NO OIL OBSERVED	Vegetated	154 / 420	12 / 14	11 / 54	6 / 5	0 / 0
	Non-Vegetated	41 / 10	7 / 28	8 / 30	35 / 75	0 / 0
NOT SURVEYED	Vegetated	72 / 167	7 / 3	9 / 7	88 / 78	14 / 0
	Non-Vegetated	4 / 0	0 / 0	0 / 0	62 / 8	37 / 0
	TOTAL	**667 / 1317**	**81 / 122**	**95 / 216**	**264 / 236**	**68 / 0**

Table 2. Summary statistics of submerged sediment ambient representative tPAH concentrations.

State	Habitat	Distance to Shore (m)	Sample Size	tPAH Concentrations (ppb)			
				Average	Standard Deviation	Min	Max
Louisiana	Un-vegetated	0-50	4	**718**	707	105	1,506
		50-500	43	**513**	664	0	2,067
	Mainland Herbaceous Salt Marshes	0-50	58	**264**	422	8	2,934
		50-500	106	**167**	125	9	828
	Back Barrier Herbaceous Salt Marshes	50-500	5	**41**	43	7.0	105
	Mangrove/Marsh Complex	0-50	3	**74**	1	73	75
		50-500	6	**109**	109	7	238
	Delta Phragmites	0-50	59	**3,015**	3,049	206	13,521
		50-500	57	**1,818**	1,920	424.9	13,130
Mississippi	Un-vegetated	0-50	11	**1,755**	3,313	3	9,780
		50-500	26	**67**	189	0	772
Alabama	Un-vegetated	0-50	8	**124**	218	0	640
		50-500	38	**68**	130	0	526
Florida	Un-vegetated	0-50	45	**100**	201	0	896
		50-500	58	**152**	412	0	2,084

Table 3. Summary statistics of 2010 post-spill submerged sediment tPAH concentrations.

State	Habitat	Shoreline Oiling Exposure	Distance to Shore (m)	Sample Size	tPAH Concentrations (ppb)			
					Average	Standard Deviation	Min	Max
Louisiana	Un-vegetated	HEAVIER PERSISTENT OILING	0-50	4	**221**	188	0	455
		HEAVIER OILING	0-50	9	**3,284**	9,725	0	29,217
			50-500	16	**280**	389	0	1,573
		LIGHTER OILING	0-50	17	**4,802**	7,789	0	27,565
			50-500	12	**665**	690	0	1,664
		NO OIL OBSERVED	0-50	1	**0**			
	Mainland Herbaceous Salt Marshes	HEAVIER PERSISTENT OILING	0-50	26	**638**	561	35	2,418
			50-500	13	**373**	337	0	1,240
		HEAVIER OILING	0-50	89	**5,434**	30,912	0	266,031
			50-500	5	**97**	23	59	116
		LIGHTER OILING	0-50	69	**2,752**	6,800	30	38,515
			50-500	2	**0**	0	0	0
		NO OIL OBSERVED	0-50	17	**423**	368	0	1,326
			50-500	20	**64**	88	0	251
	Back Barrier Herbaceous Salt Marshes	HEAVIER OILING	0-50	5	**150**	108	31	246
			50-500	4	**53**	42	7.0	105
		LIGHTER OILING	0-50	3	**326**	208	130	544
			50-500	1	**31**		31	31
		NO OIL OBSERVED	0-50	2	**332**	156	221	442
			50-500	2	**18**	1.6	17	19
	Mangrove/Marsh Complex	HEAVIER PERSISTENT OILING	0-50	9	**117**	25	83	154
			50-500	2	**306**	401	23	590
		HEAVIER OILING	0-50	1	**151**		151	151
		LIGHTER OILING	0-50	4	**285**	146	153	420
			50-500	1	**0**		0	0
		NO OIL OBSERVED	50-500	2	**14**	20	0	28
	Delta Phragmites	HEAVIER PERSISTENT OILING	0-50	6	**915**	449	259	1,393
		HEAVIER OILING	0-50	22	**2,056**	2,399	223	10,264
		LIGHTER OILING	0-50	5	**1,508**	939	762	3,135
		NO OIL OBSERVED	0-50	6	**583**	384	190	1,139
			50-500	4	**176**	94	119	315
Mississippi Alabama Florida	Un-vegetated	HEAVIER PERSISTENT OILING	0-50	1	**0**			
		HEAVIER OILING	0-50	18	**41**	82	0	296
			50-500	37	**77**	196	0	832
		LIGHTER OILING	0-50	42	**115**	437	0	2,250
			50-500	38	**63**	200	0	1,107
		NO OIL OBSERVED	0-50	8	**23**	52	1	151
			50-500	11	**75**	131	2	434

Table 4. Weighted summary statistics of 2011 MESSh submerged sediment tPAH concentrations.

State	Habitat	Shoreline Oiling Exposure	Distance to Shore (m)	Sample Size	tPAH Concentrations (ppb) Average	Standard Error	Min	Max
Louisiana	Un-vegetated	HEAVIER PERSISTENT OILING	0-50	15	**108**	22	0.5	2,186
			50-500	2	**1**	0.1	1	1
		HEAVIER OILING	0-50	36	**85**	8	0.2	936
			50-500	29	**90**	13	1	823
		LIGHTER OILING	0-50	30	**642**	258	0.2	15,646
			50-500	23	**1,940**	520	0.4	14,068
		NO OIL OBSERVED	0-50	24	**254**	39	29	1,506
			50-500	5	**395**	223	84	1,656
	Mainland Herbaceous Salt Marshes	HEAVIER PERSISTENT OILING	0-50	97	**1,143**	576	20	81,862
			50-500	30	**261**	21	29	574
		HEAVIER OILING	0-50	71	**907**	179	5.6	26,900
			50-500	13	**109**	21	31	828
		LIGHTER OILING	0-50	68	**268**	6.8	7.9	3,718
			50-500	18	**179**	33	28	698
		NO OIL OBSERVED	0-50	54	**401**	90	26	10,576
			50-500	14	**317**	8.9	78	453
	Back Barrier Herbaceous Salt Marshes	HEAVIER OILING	0-50	3	**41**	25	4.3	89
			50-500	1	**24**		24	24
		LIGHTER OILING	0-50	9	**113**	46	3.7	965
			50-500	1	**9.3**		9.3	9.3
	Mangrove/Marsh Complex	HEAVIER PERSISTENT OILING	0-50	6	**100**	9.9	70	262
		HEAVIER OILING	0-50	34	**264**	50	23	1,695
			50-500	4	**52**	26	6.9	129
		LIGHTER OILING	0-50	30	**497**	264	55	9,736
			50-500	8	**179**	5.0	134	325
		NO OIL OBSERVED	0-50	28	**144**	9.2	44	395
			50-500	12	**165**	15	97	301
	Delta Phragmites	HEAVIER PERSISTENT OILING	0-50	5	**672**	318	77	1,333
			50-500	1	**1,231**		1,231	1,231
		HEAVIER OILING	0-50	31	**1,538**	321	27	8,889
			50-500	9	**506**	288	24	2,121
		LIGHTER OILING	0-50	42	**1,212**	46	604	3,764
			50-500	15	**1,068**	212	35	4,560
		NO OIL OBSERVED	0-50	94	**2,276**	216	145	13,521
			50-500	42	**1,701**	156	425	13,130
Mississippi Alabama Florida	Un-vegetated	HEAVIER PERSISTENT OILING	0-50	1	**0.9**		0.9	1
			50-500	3	**9**	4	0.4	66
		HEAVIER OILING	0-50	79	**59**	33	0	11,830
			50-500	34	**208**	100	0	21,332
		LIGHTER OILING	0-50	63	**8**	2	0	156
			50-500	31	**100**	21	0	2,084
		NO OIL OBSERVED	0-50	56	**105**	6	0.1	1,738
			50-500	26	**14**	5	0.01	277

Table 5. Summary statistics of petrogenic PAH depletion rates along Louisiana mainland herbaceous salt marsh shorelines.

Year	Matrix	Position	Sample Size	Petrogenic PAH Depletion (%)			
				Average	Standard Deviation	Min	Max
2010	Marsh Soil	Zone 3	35	97.5	1.0	94	99
		Zone 2	38	97.5	0.8	95	99
		Zone 1 (Edge)	40	95.7	2.2	90	98
	Submerged Sediment	0-50 m from Shore	90	95.8	2.2	87	99
		50-500m from Shore	11	97.5	1.1	95	99
2011	Marsh Soil	Zone 3	36	97.5	1.8	91	99
		Zone 2	38	97.7	1.3	94	99
		Zone 1 (Edge)	37	96.7	1.6	93	99
	Submerged Sediment	0-50 m from Shore	103	97.2	1.6	87	99
		50-500m from Shore	25	97.4	0.6	96	98